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AUTOMATIC ASCENT FLIGHT DESIGN

WHITE PAPER ON

OPERATIONAL EFFICIENCY : AUTOMATIC ASCENT FLIGHT DESIGN

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Mission Planning and Analysis
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1. INTRODUCTION

The expected increase in launch vehicle operations to support Space Station Freedom and a Lunar/Mars exploration initiative will require a more efficient approach to ascent flight design and operations. This paper presents a concept of continuous improvement in ascent flight design through an evolutionary process beginning with today's vehicles (Shuttle and expendable (ELV's)) and continuing into the next century with the Advanced Launch System (ALS) and Advanced Manned Launch System (AMLS). Figure 1 provides a pictorial view of the improvement path to be described in the following sections.

Improvements in launch probability, quality assurance, training techniques, and on-board autonomy will have to be made while simultaneously reducing operations costs and time lines. Attaining this considerably higher level of efficiency and speed will require an infusion of advanced technology in the form of automated flight design software tools, adaptive GN&C algorithms, advanced atmospheric sensors and improved on-board computational capabilities.

Section 2 describes the detailed objectives necessary to obtain efficiency improvements. Section 3 outlines the technology milestones along this evolutionary path and summarizes the accomplishments to date. Section 4 discusses the technology issues which must be addressed. Section 5 provides the candidate launch vehicle programs to be considered for this technology. Section 6 lists the key NASA contacts and Section 7 summarizes the paper.

2. OBJECTIVES

The objective of this concept is to significantly reduce the cost of ascent flight design while simultaneously reducing the required process time line and to significantly improve operations responsiveness and flexibility.

Today's ascent flight design process is characterized by extensive manpower and lead times of up to a year. Driving the lead time is the flight code re-configuration and mission control (and crew for Shuttle) training requirements. On-board G&C algorithms are generally non-adaptive for the atmospheric portion of flight, resulting in low probability of launch during seasons with dynamic upper atmosphere wind profiles. For Shuttle, multiple intact abort sites require extensive trajectory analysis to determine targeting values for the on-board computers. This combination of characteristics results in a process that requires significant engineering manpower to be applied many months prior to launch. If the launch date or other mission parameters change, many of these activities will have to be repeated.

To improve this process, changes must be made in a number of areas. Ascent flight design software tools need to be automated and re-hosted in state-of-the-art distributed computer systems. Launch probability can be increased by developing faster upper atmosphere wind measuring systems and modifying on-board G&C systems such that the vehicle can adapt to near launch time changes in the atmosphere. Mission control and crew training tools and techniques need to be standardized to relieve the analysis burden of the flight planners.

Finally automated flight design quality assurance approaches have to be developed that can certify

launch readiness without requiring tremendous amounts of engineering manpower.

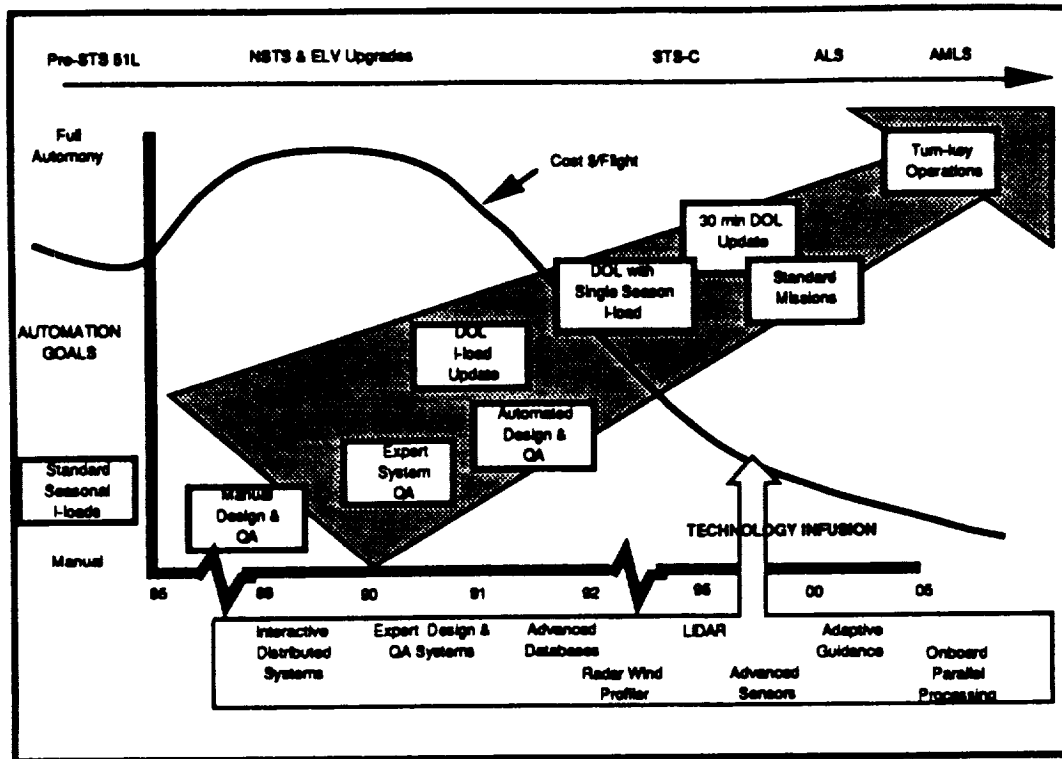


Figure 1 - Flight Design Improvement Path

3. TECHNOLOGY MILESTONES

The objectives described in the previous section can be organized into a number of technical milestones each incorporating specific capabilities. These milestones, taken together, constitute an evolutionary path. An overview of this path is provided in Figure 2. The following paragraphs describe the required technologies and suggested implementation strategies.

3.1 Automated Ascent Flight Design

For Shuttle, the task of designing the ascent trajectory has evolved from the engineering intensive approach used for the first missions to

the current more streamlined approach, relying on standard seasonal trajectory designs. This approach has proved adequate for the launch rates experienced through the 1980's but can not cope with launch rates beyond 10 to 15 a year.

Software automation techniques coupled with state-of-the-art distributed computer systems need to be applied to this process if significant gains in efficiency are to be made.

This need is currently being addressed at JSC through several on-going activities. The Mission Operations Directorate is developing the Flight Analysis and Design System (FADS) to be the Shuttle flight design environment for the 1990's. This system will consist of a network of UNIX based

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workstations using advanced software tools to perform all of the Shuttle flight design analysis tasks. The Mission Support Directorate is developing various new applications programs that will be more autonomous than the current versions and will be targeted for hosting on the FADS system when it becomes operational in 1993.

Beyond these steps, more advanced technology will be necessary to obtain total autonomy. Innovative applications of expert systems and advanced data base technology could be used in a system which would perform the majority of the flight design tasks.

3.2 Launch Probability Improvements

Currently, today's fleet of vehicles are constrained ,by aerodynamic loads, to launching in relatively benign upper atmosphere wind conditions. For Shuttle during the winter, these conditions can occur less than 50 percent of the time. Improvement in this situation can be obtained through development of near launch time trajectory update capability and by modifying the on-board GN&C system to be insensitive to changes in the atmospheric conditions.

The Shuttle program office is currently committed to implementing a day of launch (DOL) trajectory update system by the end of 1990. This approach uses the current Jimsphere wind measuring system to provide input data to a new software program. This program produces updated first stage guidance I-Loads tailored to the measured wind. It is projected that when using a wind profile measured 3 to 4 hours prior to launch, this system can improve launch probability from 10 to 20 percent, depending on the mission.

Further improvements in launch probability, other than structural changes to the vehicle, will require new wind measuring technology and/or new approaches to on-board first stage guidance and control.

The Shuttle program office in conjunction with MSFC is testing a doppler radar wind profiler as a replacement for the current Jimsphere system. Potentially this system could prove to be faster than the balloons while maintaining the same level of measurement accuracy. Measurement speed is important. The earlier prior to launch the

measurement is taken ,the more margin for change in the wind is required. This additional margin to account for wind persistence degrades launch probability. Therefore, faster measurement means measurement closer to launch, which leads to lower wind persistence margin. The ultimate result is higher launch probability.

As part of the ALS program, another wind measurement system (LIDAR) using laser technology was being investigated. The emphasis of this activity was to develop an on-board wind measurement capability for adaptive G&C purposes. This is a technically ambitious objective, not guaranteed of success. However, this research could provide spin-off advances for ground based measuring systems in improved speed and accuracy.

The Mission Planning and Analysis Division of JSC is currently concentrating on improvements to on-board G&C algorithms that will provide more adaptability to atmospheric changes. These algorithms span the technical spectrum from simple modifications to the current G&C system, to completely closed loop algorithms requiring no pre-flight planning and maximum launch probability.

3.3 Standardized Mission Control and Crew Training

To date, control center and crew training have taken the approach of requiring the most accurate trajectory simulation possible. The rationale has been that to properly prepare the flight controllers and crew for any anomalous situations that might occur,they need the best representation of the nominal flight profile that exists. For Shuttle, this philosophy has greatly increased trajectory re-configuration costs.

The current Shuttle trajectory re-configuration process is driven to a start date many months prior to launch due to two requirements, on-board code preparation and mission control training. In Section 3.2 it was outlined how program changes are in work that will de-sensitize the vehicle from launch day atmospheric changes in order to improve launch probability. Inherent in these changes is the de-sensitizing of the on-board code from required updates induced by launch date changes. The net result of this new approach will

be more standardized flight code prepared one time prior to launch regardless of launch date. The requirement for an accurate training trajectory profile will become the driver for early flight design start dates.

Currently JSC is evolving toward a more standardized training scheme with the use of flight cycles vs. training cycles. A flight cycle is the trajectory design that will be used on the actual mission while the training cycle is only for integrated control center simulations. The difference in the two is the absence of the rigorous flight readiness verification for the training cycle. The activities associated with the flight design are identical and still need to be performed at least twice per mission.

This is a significant improvement in operations cost but has not realized all the gains that are possible. For further improvement, it will be necessary to re-examine the training requirement of best possible simulation trajectory at any cost.

In reality, the flight controllers and crew have been operating under a mis-conception. The Shuttle trajectory changes radically in the presence of different upper atmosphere winds. Since it is impossible to predict wind profiles more than a few hours in advance, all training is performed with statistical mean monthly wind profiles. The probability that the wind used for training would match the actual launch wind is extremely small. Therefore the flight controllers and crew are not training to the actual flight profile, within some tolerance, no matter how accurate a flight design is being used.

An approach using standard trajectory designs for training could be developed. Trajectory sets could be defined one time based on gross mission requirements such as orbit altitude, orbit inclination, abort selection philosophy, etc.. This approach would present just as accurate a picture of how the trajectory will look as today's technique, but at a significantly reduced cost in flight design.

3.4 Automated Quality Assurance Systems

Flight design quality assurance is the process that insures the designed trajectory meets all sub-system constraints, is compatible with the on-

board flight software, and satisfies all mission objectives. For today's fleet of launch vehicles, this process relies on intensive engineering analysis. If cost reductions are to be realized in this area without decreases in product quality, automation has to occur.

In general, any quality assurance process can be defined by a set of pass/fail criteria. Conceptually, a system could be produced that uses flight design trajectory data as input to an automated expert system. This system would apply well defined pass/fail criteria against this trajectory data and alert the expert flight designer of any rule violations. Although not removed from the process, the workload of the expert engineer responsible for quality assurance would be significantly reduced.

At JSC, the Mission Support and Mission Operations directorates are developing such a system for ascent Shuttle flight design. One of the outcomes of the rush to make the Shuttle operational was the lack of flight design process documentation. Since 1986 these two organizations have been creating a flight design quality assurance rule base which will be completed for the ascent and insertion flight phases during 1990. The next planned steps are to develop automated software applications of these rules for incorporation in the FADS distributed computer system. To date, this activity has been somewhat narrow focused to the areas of expertise of the two directorates. If maximum reductions in quality assurance costs are to be realized, this activity needs to become program wide and supported by the Shuttle program office and the integration contractor.

An area that quality assurance automation is being supported by the Shuttle program office is in the development of the day of launch trajectory update system described in Section 3.2. This system will be able to update the set of guidance I-Loads that define the first stage trajectory within a few hours of launch. This I-Load set is flight critical and a method had to be developed such that flight safety could still be assured if these I-Loads were changed. What has been adopted and is currently in development is an automated pass/fail rule base formulated by the expert G&C engineers currently responsible for flight readiness assessments. This automated process will be operational when this trajectory update capability comes on line in late 1990.

MAJOR MILESTONES (1990-2005)		
<u>Technology Availability:</u>	<u>Products:</u>	
<ul style="list-style-type: none"> • Interactive / Distributed Systems • Flight Design Expert Systems • Advanced DB's for Flight Design • Radar Wind Profiler • Adaptive Guidance Algorithms • LIDAR Technology • Advanced Sensors • Flight Qualified Parallel Proc. 	<ul style="list-style-type: none"> • Day of Launch I-load Update • Expert System I-load Verif. • Auto I-load Design • FADS • FSW for single season I-load • 30 min DOL I-load Design • Onboard Autonomy 	Today 1990 1991 1992 1993 1995 1997 1998 2000 2005

Figure 2 - Technology Milestones

4. TECHNOLOGY ISSUES

In order to reach the objectives defined in Section 2, two major technology issues need to be resolved; significantly faster measurement of upper atmosphere winds without reducing accuracy and significantly higher levels of on-board computation capability. It is felt that technology improvements in these areas combined with state-of-the-art technology in computer systems for analysis, state-of-the-art software approaches and a commitment of resources to the effort will bring about the changes necessary to reach really low levels of operations cost per flight.

As discussed in section 3.2, a fast, accurate upper atmosphere wind measuring system would increase launch probability by reducing the margin required to protect for changes in the wind. If a system could be produced that would support measurement less than 30 minutes prior to launch, launch probability degradation due to wind persistence would nearly be eliminated. The demonstration activities by NASA on radar wind profilers and the ALS program on LIDAR should be actively supported as the right steps toward this goal.

All of today's launch vehicles use on-board computers developed prior to the early 1970's. The tremendous increases in computational speed and storage capacity occurring in the late 1970's and 80's need to be exploited for the next generation of vehicles. Technologies such as parallel processing have produced commercial machines with thousands of times the speed and storage capability of the Shuttle GPC's at a fraction of the size, weight and power requirements. This type of technology should be actively applied to on-board flight and space rated systems. The level of computation capability currently available commercially if applied on-board would allow near complete autonomy and elimination of major portions of the real time flight support necessary today.

5. CANDIDATE PROGRAMS

Generally the topics addressed in this paper could be applied to any launch vehicle in today's fleet or that might be developed in the future. However, retro-fitting some of these concepts into a mature

design may be more costly than any benefit that would come from the change.

For the Shuttle and possibly the existing ELV's, implementing the concepts associated with flight design and quality assurance automation, launch probability improvement, and training standardization seem to make cost sense. Full on-board autonomy and advanced on-board computers probably should wait for the ALS and AMLS programs.

Shuttle-C, as a direct spin-off from Shuttle technology, would fall in the same category as the Shuttle and ELV's.

6. KEY NASA CONTACTS

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A. J. Bordano - JSC/FM
Mission Support Directorate

7. SUMMARY

This paper has outlined some concepts that would provide cost benefits to operations of existing launch vehicles such as the Shuttle and ELV's and new start programs such as ALS and AMLS. The technical objectives of improvements in launch probability, quality assurance, training techniques, and on-board autonomy while simultaneously reducing flight design costs will require a combination of state-of-the-art and advanced technologies.

To realize these potential gains in cost effectiveness and responsiveness to national launch rate demands, it will require a high level of commitment to developing the advanced technologies previously described in addition to support of the current ongoing activities by the Mission Operations and Support Directorates.